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INVESTIGATING THE EFFECT OF OVERALL EQUIPMENT EFFICIENCY ON THE PRODUCTIVITY OF A DIESEL POWER PLANT USING AN EMPIRICAL APPROACH

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ABSTRACT

In current competitive global market all the organisations are mainly focussing on improving their productivity in order to maintain and further increase the competitive advantage. Hence, assessment of productivity in any organisation is essential. The present work focuses on analysing the effect of human, capital and raw material input on the productivity of a diesel power plant. This analysis carried out in the industry highlights the important reasons for variations in the productivity of a diesel plant. The empirical approach adopted along with regression techniques showed that overall equipment efficiency (OEE) along with raw material availability is the main factor for the fluctuations in the output obtained from the plant.

KEYWORDS: Equipment Efficiency, Diesel Plant, Productivity & Empirical

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INTRODUCTION

The concern related to productivity is spread across all groups of people and permeates entire society. Global concern for the productivity stems from the fact that products produced by different region of the world needs to be competitive in terms of quality, technology, services and cost of production. Higher productivity will lead to higher fund generation and creates more revenue for the region. This will improve service quality and will be a step towards creating a better standard of living. As per the economists, it is a vital ingredient for the actual income of the common people. Corporate on the other hand are of the opinion that it increases competition and in order to improve profitability in that scenario, companies need to bring down production costs significantly. Technical people in the industry link the development to meeting of deadlines, improved quality of manufactured products and ultimately improving the material utilisation and decreasing the expenses.

The available resources are optimised by analysing the prominent resources to obtain better productivity. This is achieved through various applicable improvement techniques used along with creative thinking and in-depth research and development. This would not be possible without a formal management process. It involves entire management from top to bottom along with the employees working towards reduction of manufacturing, transportation and logistics costs through an amalgamation of all stages of productivity cycle. In this regard, overall equipment efficiency being a powerful tool plays an important role. It helps to identify hidden components of an inefficient usage of productive time and thereby exposing exact percentage of productive time. The OEE values have to be tracked at regular intervals to bring about significant improvements in the production process. This would be a leap towards embracing world-class lean manufacturing systems by all the organisations of

varying sizes.

A multi-unit organization having its plants located at different geographical location often observes differences in plant productivities even though organizations has taken care to have a common internal environment represented in the form of work culture, practices, traditions, style of management and management expectations. External environment has an impact on performance of the organization. It can both help in improving the performance as well as in lowering the same. External environment act as a supra-system in which an organization works as a system. Organization therefore, gets influence through interaction of various subsystem of external environment. External environment is characterized by the social beliefs, value system, culture and tradition of society. The government rules and policies, the statutory law, the labour legislation and tax structure from another dimension. The policy and political ideology adopted by the government of the land, the fiscal policy, the availability of funds are the other components of the environment.

This paper reports the work carried out in a diesel power plant. The effect of various factors influencing the productivity of prominent resources in the plant were studied and analysed. The Overall Equipment Efficiency (OEE) of various generators installed in the plant have been determined and results are presented in a graphical and tabular format.

LITERATURE REVIEW

Efficiency of a business unit is measured in-terms of a productivity index. Long term sustenance of productivity requires growth of a firm with support from management systems in terms of relevant production strategies. This can be achieved through overall improvement in methods employed by the management to deliver better total productivity (Liaw, 2001). Service industry will vouch for better productivity, as they will have significant impact on overall productivity of the economy (Berg et al, 2003).

In the competitive environment, customer satisfaction is the utmost important factor and organisations strive hard in minimising production costs using efficient techniques (Ramayah, 2002). Usually in the industries, cost of production is kept low by extending the average time between failures of the equipment. This will also lead to lowering the maintenance costs (Raouf, 1994).

The effectiveness of production equipment in production industries can be maximised using TPM approach based on OEE (Shirose, 1989). The unproductive time can be turned in to productive time thereby observing higher savings and further contributing positively to profit by increasing even one percentage in OEE score (Shetty et al, 2010). Comparison of different sites in a big organisation can be carried out using OEE rating. It will also play an important role in deciding on strategic investment and related management decisions (Mileham, 1997). It is observed that perspective of service industries in terms of productivity should be from both company and customer angle. This has many added benefits like reconciliation of conflicts, better leverage thereby improving quality of service and enhancing service productivity. A conceptual frame work incorporating the previously mentioned scenarios and its implications have also been reported (Parasuraman, 2002).

Shaw emphasizes the Quality-Productivity connection and lay stress that a successful organization has a winning combination of the both. Shaw also detailed the quality characteristics that comprises of customer perception, product reliability, value and warranty. Shaw has expressed the connection in equation 1 as,

$$Q \, U \, P \sim P_1 \tag{1}$$

Where,

Q = Quality as perceived by customer

P = Productivity as reflected in employee output

P_1= Profitability

In a simple expression, quality has also been referred to as 'fitness for use'. Quality encompasses requirement of product durability, usability, maintainability, reliability in a given frame work of costs and specified attributes. In totality of performance objectives, it should satisfy market needs, provide safety to personnel, satisfy design, specifications, permit expectation of longer life of the product etc. A higher output per unit of input or reduced input cost per unit of output should not be deemed as higher productivity if the same has been accomplished at the cost of quality (Vratetal, 1998).

METHODOLOGY

A descriptive type production model is used for the measurement of productivity. The input measurements for the model are man time, machine time and equivalent of man power. Firm's output can be expressed in terms of production units, its monetary value as well as corrected monetary value in standard hours. The output and input of a firm is common unit of measurement. The equations 2 to 6 are used for calculating productivity and its index.

$$\text{Human factor} = \frac{\text{Overall output}}{\text{Human input}} \tag{2}$$

$$\text{Material factor} = \frac{\text{Overall output}}{\text{Raw material input}} \tag{3}$$

$$\text{Capital factor} = \frac{\textit{Overall output}}{\text{Capital input}} \tag{4}$$

$$\text{Miscellaneous factor} = \frac{\text{Overall output}}{\text{Capital input}} \tag{5}$$

$$\text{Total productive factor} = \frac{\text{Overall output}}{(\text{Human}+\text{Capital}+\text{Material}+\text{Miscellaneous})\text{ input}} \tag{6}$$

The present study is designed to assess the productivity at organization level. Correlation analysis, Regression analysis and forecasting models will be used in the analysis of the data. OEE has been computed from eight generators data collected for a period of three-years.

Multiple regression analysis is used to estimate the value of dependent variable Y. Equation 7 is used to calculate value of P at i^{th} point.

$$\widetilde{P} = x + y_1 * A_{1i} + y_2 * A_{2i} + y_3 * A_{3i} \tag{7}$$

where, A_{2i} and A_{3i} are the values of first, second and third independent variable respectively at i^{th} point. Similarly, y_1, y_2 and y_3 are the slope associated with X_{1i}, X_{2i} and X_{3i} respectively. Error is denoted by letter e_i.

$$e_i = (P_i - \widetilde{P}_i) \tag{8}$$

$$\text{Also, } y = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} (P_i - \widetilde{P}_i)^2 \tag{9}$$

On substituting equation 8 in equation 9, equation 10 is obtained

$$= \sum_{i=1}^{N} (P_i - x - y_1 * A_{1i} - y_2 * A_{2i} - y_3 * A_{3i})^2 \quad (10)$$

Partial differentiation of y with x, b_1, b_2 and b_3 and equating it to zero will give minimum value of y. The resulting normal equations are numbered as 11.

$$\sum_{i=1}^{N} P_i = N * x + y_1 * \sum_{i=1}^{N} A_{1i} + b_2 * \sum_{i=1}^{N} A_{2i} + y_3 * \sum_{i=1}^{N} A_{3i}$$

$$\sum_{i=1}^{N} P_{i\,x} A_{1i} = x * \sum_{i=1}^{N} A_{1i} + y_1 * \sum_{i=1}^{N} (A_{1i})^2 + y_2 * \sum_{i=1}^{N} (A_{2i} * A_{3i}) + y_3 * \sum_{i=1}^{N} (A_{3i} * A_{2i})$$

$$\sum_{i=1}^{N} P_{i\,x} A_{2i} = x * \sum_{i=1}^{N} A_{2i} + y_1 * \sum_{i=1}^{N} (A_{1i} * A_{2i}) + y_2 * \sum_{i=1}^{N} (A_{2i})^2 + y_3 * \sum_{i=1}^{N} (A_{3i} * A_{2i})$$

$$\sum_{i=1}^{N} P_{i\,x} A_{1i} = x * \sum_{i=1}^{N} A_{3i} + y_1 * \sum_{i=1}^{N} (A_{1i} * A_{3i}) + y_2 * \sum_{i=1}^{N} (A_{2i} * A_{3i}) + y_3 * \sum_{i=1}^{N} (A_{3i})^2 \quad (11)$$

Equation 11 is used to obtain the values of x, b_1, b_2 and b_3. These values are used to formulate linear equation 12.

$$P_i = x + y_1 * A_{1i} + y_2 * A_{2i} + y_3 * A_{3i} \quad (12)$$

Further, correlation analysis is conducted for determining the coefficients of determination and correlation. Both equations 13 and 14 are used to compute r2 as shown in equation 15. Because one minus ratio between two variations obtained from equations 13 and 14 is the coefficient of determination.

$$\sum (Y - \hat{Y})^2 \quad (13)$$

$$\sum (Y - \bar{y})^2 \quad (14)$$

$$r^2 = 1 - [\sum (Y - \hat{Y})^2 / \sum (Y - \bar{y})^2] \quad (15)$$

Forecast is expressed mathematically in equation 16.

$$F(t+1) = \alpha Y_t + (1 - \alpha) F_t \quad (16)$$

The computation of OEE is composed of availability, performance and quality rate as shown in equation 17. The computation of availability, performance and quality rate is carried out using equations 18 to 23.

Overall Equipment Efficiency (OEE)= Availability(A) X Performance(P) X Quality rate (Q)(17)

$$\text{Availability (A)} = \frac{\text{Time available for production} - \text{Down Time}}{\text{Time available for production}} \quad (18)$$

Performance Efficiency (PE) = Rate Efficiency (RE) x Speed Efficiency (SE) (19)

Rate Efficiency (RE)= Actual cycle time/Design cycle time (20)

Design cycle time= (Generator running time per year) + (No of times generator was run x Activation time of generator (Secs) x 1/3600) (21)

Speed Efficiency (SE) = Max output produced/ Max design output (22)

Quality rate (Q) = No. of good items/Total No. of items (23)

RESULTS AND ANALYSIS

The results of the total productive index computation are given in the table 1.

Table 1: Total Productive Index Computation

	Details	First year Rs (in Lakhs)	Second year Rs (in Lakhs)	Third year Rs (in Lakhs)
A	Overall output	18634	22681(lakhs)	48037
B	Human Input	267	416	472
C	Capital Input	373	793	882
D	Material Input	17498	23597	45071
E	Miscellaneous Input	15	19	26
F	Total Input	18153	24825	46450
Human factor (A/B)		69.79	54.52	101.77
Capital factor (A/C)		49.96	28.6	54.46
Material factor (A/D)		1.06	0.96	1.07
Miscellaneous factor (A/E)		1242.27	1193.74	1847.58
Total Productive factor (A/F)		1.03	0.91	1.03
Human Index (HI)		1	0.78	1.46
Capital Index (CI)		1	0.57	1.09
Material Index (MI)		1	0.91	1.01
Miscellaneous Index (MSI)		1	0.96	1.49
Total Productive Index (TPI)		1	0.88	1
% change in total productivity			11.7	13.19

Total productivity decreased by 11.7% during the second year when compared with first year. Total productivity increased by 13.19% during the third year when compared with second year.

Table 2: Computation of Various Indices

Period	TPI(P)	HI(A_1)	CI(A_2)	MI(A_3)	MSI(A_4)	A_1^2	A_2^2	A_3^2	A_4^2
First year	1	1	1	1	1	1	1	1	1
Second year	0.88	0.78	0.57	0.91	0.96	0.61	0.32	0.83	0.92
Third year	1	1.46	1.09	1.01	1.49	2.13	1.19	1.02	2.22
∑ Sum	2.88	3.24	2.66	2.92	3.45	3.74	2.51	2.85	4.14

Table 3: Multiple Regression Calculation Continuation

Term	A_1A_2	A_2A_3	A_3A_4	A_4A_2	A_1A_3	A_1A_4	PA_1	PA_2	PA_3	PA_4
First year	1	1	1	1	1	1	1	1	1	1
Second year	0.44	51.87	0.87	0.55	0.71	0.75	0.69	0.5	0.8	0.84
Third year	1.46	1.1	1.5	1.62	1.47	2.18	1.46	1.09	1.01	1.49
∑ Summation	2.9	3.97	3.37	3.17	3.18	3.93	3.15	2.59	2.81	3.33

Table 2 and 3 shows the calculation multiple regression analysis. The constants x, y_1, y_2, y_3 and y_4 are obtained from equation 11and the values are used formulate equation number 24.

$$P_i = -0.001 - 0.079\,(HI) - 0.070\,(CI) + 0.943\,(MI) + 0.166\,(MSI) \quad (24)$$

The standard deviation values obtained from the equation 24 are shown in table 4.

Table 4: Standard Deviation of Productivity Indices

Type	Standard Deviation.
TPI	0.9154
HI	0.4244
CI	0.2641
MPI	0.2924
MSI	0.4062

Table 5: Correlation Analysis Table

Factor	TPI
TPI	1.0000
HI	0.1237
CI	0.0900
MPI	0.2038
MSI	0.1073

Table 4 shows that material and human inputs have higher correlation with total productivity. Emphasis of the management should be on the above two factors to improve total productivity and Table 5 shows that the factors which have higher correlation needs to be monitored closely by giving more attention. Increased motivation, better training, providing job enrichment, improved quality circle, better financial incentives and good promotion policy will lead to improved human input. Similarly, improvement in material input can be obtained by wastage reduction, better control of inventory and quality. Improved machine maintenance, reduced number of idling machines and infrastructure are reasons for improving capital productivity. Reduction in overheads, losses, wastages complemented by better marketing practices and excellent welfare facilities will give rise to higher miscellaneous productivity.

Forecasting of total productivity for each year is obtained by using equation 16. The value of α is chosen as 0.2. The values computed are given in Table 6.

Table 6: Forecasting Table

Period	TP (P)	Forecast F	Error	Absolute Error	Squared Error
First Year	**1.03**	-	-	-	-
Second Year	**0.91**	**1.03**	**-0.12**	**0.12**	**0.014**
Third year	**1.03**	**1.01**	**0.02**	**0.02**	**0.0004**
Current year	-	**1.014**	-	-	-

Table 6 shows that forecasted total productivity value for the current year is 1.014. The overall efficiency of generators has been computed from the data collected from organisation regarding the performance of the eight generators installed in the plant.

Table 7: OEE of Eight Generators during First Year Period

Variables / Production Parameters		Diesel Generators							
	Eq No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Availability									
Total Running Time (hrs) (TRT)		7468	3337	3241	5301	3912	3445	3818	3902
Down time (hrs)		6327	758	622	3741	723	586	1692	993
Available in hrs A	2	1096	2579	2619	1560	3189	2859	2126	2909
Available in % Availability	**A/TRT**	15	77	81	29	82	83	56	75
Performance Efficiency									
Actual Cycle Time (hrs)		7468	3337	3241	5301	3912	3445	3818	3902
Design cycle Time (hrs)	5	7486	3355	3259	5319	3940	3463	3836	3920
Rate efficiency (RE)	4	1	1	0.99	1	0.99	1	1	1

Table 7: Contd.,									
Max. Output Produced (MW)		16	16	16	16	16	16	16	16
Max. Design Output (MW)		18	18	18	18	18	18	18	18
Speed Efficiency (SE)	6	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Performance efficiency (PE)	3	0.89	0.89	0.88	0.89	0.88	0.89	0.89	0.89
Quality Rate(Q)									
Q	7	100%	100%	100%	100%	100%	100%	100%	100%
OEE	1	13	68.4	71.4	26.1	72	73.5	49.3	66

Analysis of the OEE values of the eight generators are given in Table 7 and the results are shown as follows:

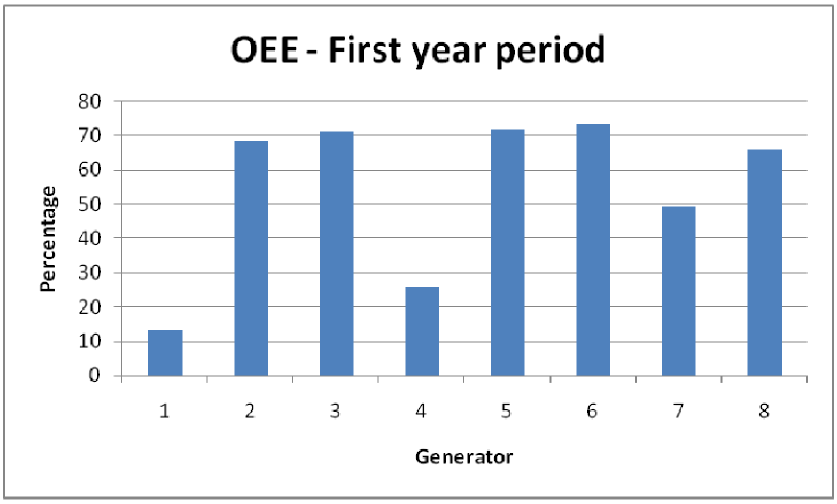

Figure 1: Percentage Distributions of OEE Values for First Year Period.

Figure 1 shows the percentage distributions of OEE values for first year period. It is inferred from figure 1 that the generator for number 6 exhibits highest OEE (73.5%) followed by generator number 5 with 72% efficiency. The other generators showed no:3 (71.4%), no: 2 (68%) OEE values respectively. This problem identified was to focus on the availability of generators 1 and 4 by incorporating appropriate maintenance methods to improve the OEE of generators.

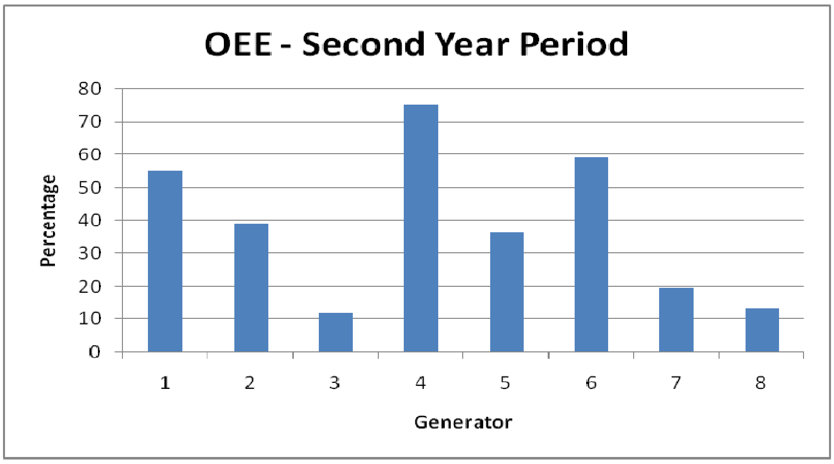

Figure 2: Percentage Distributions of OEE Values for Second Year Period.

Figure 2 shows the percentage distributions of OEE values for second year period. In the second year, generator no: 1 was not available continuously for production due to breakdown. After comparing the OEE values for the years for the three-year period, it is found that all generators are not showing consistent performance due to no availability of machines on account of breakdown maintenance.

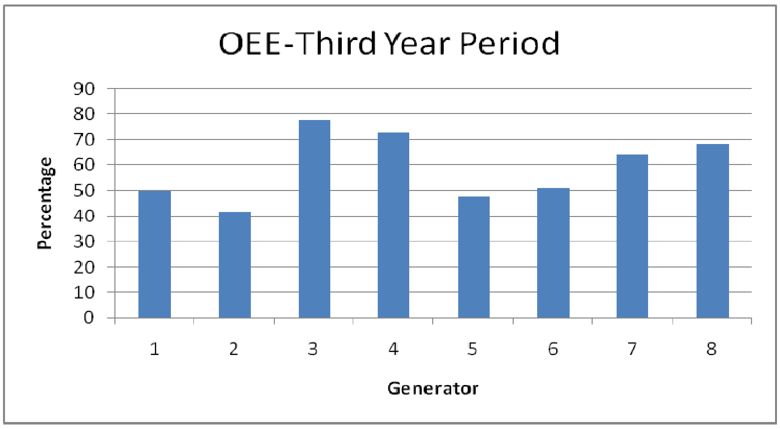

Figure 3: Percentage Distributions of OEE Values for Third Year Period.

Figure 3 shows the percentage distributions of OEE values for third year period. Less spacing of installed generators (approximately 3m), generators get overheated and it leads to scheduled maintenance work mandatory for equipment. In this case, a vapour absorption air condition system has to be installed with at least 10 m spacing and system can make use exhaust gas of the generator. This facilitates a better OEE.

CONCLUSIONS

Important conclusions drawn after conducting a detailed study in diesel power plant are given below.

- Total productivity has seen a variation in the three-year period,
- There is a decrease of total productivity by 11.7% during the 1st year compared to second year and total productivity increased by 13.19% during the third year compared to second year.
- There is a highest correlation between material input and total productivity.
- Total productivity for current year has been determined using forecasting model as 1.014.
- Improper maintenance has resulted in eight generators not showing consistent performance during the three -year period.

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